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Survival of Thin Films in Space

by

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Introduction

During the past six years this laboratory has accumulated many months of radiation observations with earth satellites and with the interplanetary space probe Mariner II using detectors whose sensitive volumes were exposed directly to outer space through thin films of metal or mica. No one of these detectors has suffered a failure, such as would result from puncture of the film. It is thought that a summary of the pertinent data may have some direct practical interest to other experimentalists and also may provide a small contribution to knowledge of the flux of micrometeoroids in space. [See the excellent review by Alexander, McCracken, Secretan, and Berg, 1963.]

Exposures with Earth Satellites

Pertinent data come from:

(a) The CsI scintillator in Explorer IV, 26 July 1958 to 21 September 1958 (57 days) [Van Allen, McIlwain, and Ludwig, 1959]. Approximate orbital parameters: Altitude of perigee 257 km by altitude of apogee 2140 km by inclination 51°. A hole in the protective foil of diameter of the order of the foil thickness would have resulted in strong optical response to sunlight; such a response was not observed.

(b) One thin-windowed Geiger tube in Injun I, 29 June 1961 to 28 August 1962 (425 days) [Frank and Van Allen, 1963], 880 km by 1000 km by 67°. A puncture of this window would have released the fill gas, thus causing an immediate, catastrophic failure; no such failure was observed during the operating lifetime of the satellite. This statement applies to all subsequent items of this listing.

(c) One thin-windowed Geiger tube in TRAAC, 15 November 1961 to 12 August 1962 (270 days) [Pieper, Williams, and Frank, 1963], 950 km by 1110 km by 32°.

(d) Three thin-windowed Geiger tubes in Injun III, 13 December 1962 to 30 September 1963 (291 days) [O'Brien, Laughlin, and Gurnett, 1964], 240 km by 2700 km by 70°.

(e) Two thin-windowed Geiger tubes in Explorer XIV, 2 October 1962 to 8 August 1963 (310 days) [Frank, Van Allen, Whelpley, and Craven, 1963], 280 km by 98,530 km by 33°.

Satellites (a), (b), (c), and (e) were either spinning or spinning and tumbling in such a way that exposure of the window may be considered to have been "randomly" oriented. Satellite (d) had one axis continuously aligned with the geomagnetic field but again, for the present purpose, may be considered to have provided a randomly oriented exposure.

The scintillator of Explorer IV was shielded by 0.2 mg/cm^2 of aluminum over which was a foil of 0.8 mg/cm^2 of nickel. All of the Geiger tubes had a mica window of 1.2 mg/cm^2 thickness (4.3 microns or 0.17 mil).

Table I summarizes the integrated "exposures" in m^2 sec sterad. The effective exposures are obtained by multiplying the actual exposures by a factor, less than one, estimated to correct for geometric shielding by the solid earth and its dense atmosphere.

The sum of the effective unidirectional exposures is 230 m^2 sec steradian.

TABLE I

Summary of Exposures in Earth Satellites

	Exposure Time $\times 10^{-6}$	Geometric Factor $\times 10^{2}$	Actual Unidirectional Exposure	Effective Unidirectional Exposure
	sec	cm^2 sterad	m^2 sec sterad	m^2 sec sterad
(a) Explorer IV	4.92	2.35	12	9
(b) Injun I	36.7	1.5	55	41
(c) TRAAC	23.3	2.2	51	38
(d) Injun III	25.1	0.6 1.1 5.0	15 28 126	129
(e) Explorer XIV	26.8	0.2 0.3	5 8	13
Sum			300	230

Interplanetary Exposure

Pertinent data came from:

One thin-windowed (also 1.2 mg/cm^2 mica) Geiger tube in Mariner II, 27 August 1962 to 29 December 1962 (124 days) [Van Allen and Frank, 1962]. During this flight period the detector was carried through interplanetary space over the heliocentric radial distance range 1.0 to 0.7 A.U. The trajectory was approximately in the ecliptic plane. The 90° full-angle conical collimator had its axis at 70° from the spacecraft-sun line throughout the flight. During the early half of the flight the collimator was directed in the generally forward direction along the orbit (subject to retro-grade meteoroid impacts) and during the latter half of the flight, in the generally backward direction (subject to pro-grade meteroid impacts), with a few days transition period of rotation about the spacecraft-sun line in mid flight. The Geiger tube operated properly throughout the flight. Table II gives the exposure data.

An explicit micro meteoroid experiment was also carried on Mariner II [Alexander, 1962].

Some Interpretative Remarks

The foregoing data have direct practical significance in establishing a certain level of confidence for experimentalists who are engaged in the design of space equipment involving thin films.

Also, they provide crude upper-limit data on the flux of micrometeoroids in space. On the basis of the review paper by Alexander et al. [1963], it appears that the impact of a meteoroid of mass exceeding 10^{-9} gram at an adopted velocity of 30 km/sec is necessary to puncture the films used in the series of flights reported herein.

The Poissonian probability P_o of the occurrence of no event in an experiment in which x events are "expected" is $P_o = \exp(-x)$; or $x = -\log_e P_o$, where x in the present context is the product of the average flux F by the exposure E. In an experiment in which no event occurs, it is usually agreed that a generous upper limit on x corresponds to $P_o = 0.05$ --that is, to $x = F \cdot E = 3.0$. The data of Tables I and II therefore provide the following upper limits on the unidirectional flux of meteoroids whose mass exceeds 10^{-9} gram (or the corresponding mass for a velocity different than 30 km/sec), averaged over time and averaged over direction as discussed above.

TABLE II

Summary of Interplanetary Exposure on Mariner II

Exposure Time: 10.7×10^6 sec

Geometric Factor: 0.2 cm^2 sterad

Total Unidirectional Exposure: 214 m^2 sec sterad

(a) At about 1000 km above the earth:

$F < 1.3 \times 10^{-2}$ (m^2 sec sterad$)^{-1}$

(or $4\pi F < 1.6 \times 10^{-1}$ (m^2 sec$)^{-1}$).

(b) In interplanetary space (1.0 to 0.7 A.U. from the sun):

$F < 1.4 \times 10^{-2}$ (m^2 sec sterad$)^{-1}$

(or $4\pi F < 1.8 \times 10^{-1}$ (m^2 sec$)^{-1}$).

Upper limit (a) is approximately equal to positive determinations as given in Figures 2 and 3 of Alexander et al. [1963]. Upper limit (b) is consistent with, but several orders of magnitude greater than the preliminary estimate of Alexander [1962] using data from his cosmic dust experiment on Mariner II.

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